

6.0 RECOMMENDATIONS

The R&D elements presented in chapter 5 will require a robust, coordinated effort by the multiple Federal agencies engaged in research, development, or application of ATD modeling systems. No one agency holds all the capabilities needed to affect the recommended course of action. Shared responsibilities, shared vision, and shared resources are essential to success. Without the resource base and sustained direction that a well-coordinated Federal effort can provide, the R&D needs cannot be met within time horizons consistent with national policy priorities.

In this chapter, the JAG presents nine recommendations, covering implementation efforts in seven areas:

- Quantify model uncertainties and interpret their implications to users;
- Capture and use existing data sets;
- Implement ATD test beds,
- Develop standards for evaluating modeling system performance;
- Improve the spatial and temporal scale interactions between meteorological and ATD models;
- Improve measurement technologies; and
- Design and conduct special studies and experiments.

Implementing these recommendations will require sustaining the effort over more than a decade. Some of the actions can be accomplished and will produce returns in the near term: within the next 2 years. Other actions will provide interim benefits at intervals along the way, even though the most significant benefits may require a decade or longer for realization. A paragraph on timing considerations follows each recommendation below.

Many of the capability limitations identified in this report are systemic, resulting from a lack of coordinated effort across agency R&D programs aimed at understanding and modeling the fundamental drivers of ATD processes, such as boundary-layer processes. Coordinated efforts are also needed to develop capabilities to measure the spatial and temporal variability of the most changeable part of the atmosphere at the resolution required for ATD predictions. These limitations can be surmounted, but success will require commitment and coordination of resources and facilities. Particularly important are the human resources residing in dedicated teams with strong operational and science motivations.

6.1 Quantify Model Uncertainties and Interpret Their Implications to Users

The JAG views the two recommendations in this section as together forming the keystone for delivering vastly more useful ATD modeling products as operational tools for the user communities described in Chapter 2. The remaining recommendations define enabling science and technology to achieve the full potential of these keystone recommendations.

6.1.1 Improve ATD Modeling Systems to Routinely Quantify Uncertainties

As explained in chapter 2, most of what users need from the ATD modeling system embedded in their consequence assessment system comes down to predicting airborne concentrations of hazards as a function of space and time. To deal with the uncertainties in predicting these concentrations, the ATD model developer has a growing array of probabilistic techniques available. Yet, the users do not want mathematical expressions of uncertainty or probability; they want answers on which to base decisions and take action. The usual practice has been to give users point estimates of concentration, whether those estimates were derived from deterministic representations of the physical ATD processes or incorporated modeling of stochastic processes. However, the uncertainties in the data inputs to the ATD model, the approximate nature of the model constructs and parameterizations, and the stochastic nature of atmospheric turbulence all lead to uncertainties in individual realizations of a model. Quantifying these uncertainties is essential for two reasons. First, reducing the uncertainty through continued R&D requires knowing how much there is and how much each factor contributes to the uncertainty in the product. Second, the ATD modeling community must do better at interpreting the implications of the uncertainty in model predictions for the users of ATD modeling products.

Recommendation 1. ATD modeling systems should routinely quantify the uncertainties in their results. Implementation actions required for this recommendation include but are not limited to the following.

- Develop robust techniques to assess probabilities of occurrence of concentrations above significant threshold levels.
- Adapt (or develop) and verify measurement capabilities at or below the scales of interest for model predictions.
- Test, verify, and validate model improvements, including probabilistic methods of process representation, parameterization, and data acceptance/assimilation.
- Establish a shared data system with substantial sets of data to test and evaluate uncertainty quantification techniques.
- Develop techniques to quantify and reduce uncertainty in predictions through improved model–data interfaces, including but not limited to sensor fusion, data assimilation, and evaluation criteria.

- Develop analysis techniques that are applicable in nonlinear regimes to display important sources of uncertainty.
- Use the outcome from new techniques for estimating uncertainty to guide improvements in ATD models.
- Develop and implement processes for uncertainty displays in data-sparse environments.

Timing considerations for recommendation 1. Initial efforts to quantify uncertainty in current models, using existing databases, can begin immediately. At reasonable funding levels, 5 years will probably be required to conduct the necessary R&D on modeling methods and to improve measurement capabilities. Delays in starting or funding limitations will extend the time required. Some of the implementation actions listed for recommendation 1 will depend on progress in other actions in the list. For instance, techniques for estimating uncertainty that are applicable in nonlinear regimes will be needed before sources of uncertainty can be ranked in importance, as a guide to improving ATD models.

6.1.2 Effective Communication of Model Uncertainties to Users

To serve users better, the model development community must do two things differently. First, modeling systems must routinely quantify the various mathematical uncertainties in model results. Second, developers must find useful ways to communicate the practical import of these uncertainties to the users. For many of the applications discussed in chapter 2, users need to understand the impact on health and safety of concentration variability in space and time. For example, a model's predicted probability distribution for the concentration in an area of interest (hazard area) during a specified time interval might be represented as the probability that a meaningful health or safety threshold concentration will be exceeded. This way of presenting model results may be practical and useful for some types of users once they understand it. Other types of users may need or prefer a different representation of results.

Ongoing, sustained interaction between developers and users is the only way to determine which representations will work best for which users, while still adequately representing the uncertainty. For example, NASA has used product advisory boards, with members drawn from the state and local governments who are the customers (potential users) for remote-sensing data. The product advisory board participates throughout the product development process, commenting at critical milestones on the members' perceptions of the value of the emerging product.

Recommendation 2. The ATD modeling R&D community should work intensively and routinely with representative users to determine effective means of presenting information to users that incorporate the quantified uncertainties in model results. Implementation actions required for this recommendation include but are not limited to the following.

- Involve users in prototyping, testing, demonstration, and training sessions for probabilistic tools under development to determine which tools and representations are most useful and acceptable to specific user types and application contexts.
- Incorporate the feedback and advice from users on the utility of representations of probability and/or measures of uncertainty into the ATD model R&D process.
- As a requirement for the ATD test bed implementation proposed in recommendation 4, require planning and implementation with relevant user communities throughout the R&D programs conducted at a test bed facility.

Timing considerations for recommendation 2. Although current capabilities to quantify the uncertainties in ATD predictions are limited, *efforts to improve on current practices in interpreting uncertainty implications for users can and must start now.* Those in the ATD model R&D community who work with users in demonstration or training exercises should take every opportunity to seek “best practices” and innovative approaches that help users understand how to accommodate prediction uncertainties in their decision processes. The dialogue among model researcher-developers, modelers (those who run the models operationally), and users of the model predictions can start immediately.

6.2 Capture and Use Existing Data Sets

An abundance of data from previous field experiments exists in various forms and formats. The richness of these experimental data has not been fully exploited, particularly given advances in analytical techniques and new objectives of analysis since the experiments were conducted. These data sets constitute the nation’s only current source of concentration data to quantify the uncertainty in ATD model predictions under actual atmospheric conditions. The studies were performed to achieve certain objectives, often related to air quality, such as estimating plume behavior in heterogeneous environments, transport and diffusion from elevated sources, or multi-state dispersion. They reflect a wide range of applications and learning conditions. However, few of these data sets have been analyzed using the probabilistic techniques now available.

These data and important unrecorded knowledge about the experiments from which they were collected are in danger of being lost to the R&D community with the aging of the experiments’ designers and participants. Individual efforts to reanalyze these legacy data sets have occurred or are in progress. An immediate effort is needed to expand and coordinate the acquisition of the legacy data sets and supporting knowledge about the experiments, capture the data and supporting information in modern data files, and analyze the data using modern approaches and techniques. The OFCM, under FCMSR instruction, could coordinate the multiagency effort needed. Appendix A describes a number of past experiments and demonstrations that this JAG views as important to capture and preserve. There may be others. Immediate action on these objectives is warranted because further work with these data sets using state-of-the-art and state-of-practice methods will aid in formulating initial estimates of the stochastic uncertainty in

ATD processes, designing ATD test beds, planning experiments for the test beds, and designing special studies and experiments.

A complementary objective to capturing and reanalyzing the legacy data sets is to increase their accessibility to the ATD modeling R&D community. For example, the OFCM could lead the effort to develop an XML standard for ATD-related data, taking into account any standards already developed or in progress for related types of data.

Recommendation 3. OFCM should convene an interagency effort to develop guidelines for acquisition, archiving, and access of data from previous field and laboratory ATD experiments. Implementation actions required for this recommendation include but are not limited to the following.

- Identify and communicate the reanalysis projects already completed or in progress.
- Prioritize the experiments and demonstrations from which data sets should be captured and preserved in accessible format.
- Adopt or adapt a data interchange standard as an archival format.

Timing considerations for recommendation 3. Data capture and archiving for the priority experiments can be completed in 3 years.

6.3 Implement ATD Test Beds

Multifunctional ATD test beds will support a variety of research, development, and product-transition activities required to fill existing gaps in meeting user needs. Among the activities enabled by ATD test beds are the following.

- Long-term measurement and archiving of measurement data on atmospheric processes and ATD modeling in urban airsheds;
- Accelerating iterative rounds of user input and feedback to implement recommendation 2;
- Accelerating user training in real environments (also essential to recommendation 2);
- Testing, evaluating, and incorporating measurement innovations;
- Developing techniques for using sources of opportunity (benign atmospheric releases, other than planned tracer studies, which can be detected and traced as they are dispersed downwind);
- Improving the assimilation of satellite-based and airborne remote-sensing data into the mesoscale meteorological models that provide input to ATD modeling systems;
- Fostering a coordinated approach to model–data interaction issues including but not limited to sensor fusion, data assimilation, and evaluation criteria;

- Providing all-season, all-weather, 24-hour quantitative data on local environmental conditions;
- Leveraging development efforts for users with diverse applications, such as weather nowcasts, air quality forecasts, public education and outreach, and transportation systems management; and
- Developing and testing methodologies for optimizing observational network design in general and network designs for urban areas in particular.

Because of the diversity of conditions across the United States and even among its major urban centers, the JAG assumes that multiple ATD test beds will be required. Urban locations are likely to predominate, but some nonurban settings will probably be appropriate as well. The sequencing and final number of test beds to be implemented and the appropriate types of locations for them should be initial tasks for an appropriately constituted body established by the stakeholder Federal agencies and referred to here as a joint (or multiagency) test bed authority. Coordination with parallel test bed development programs for atmospheric modeling goals (e.g., air quality and weather forecast modeling) is essential to ensure that the overall investment is cost-effective and efficient.

Recommendation 4. Participating Federal agencies, through the FCMSSR, should establish a multiagency test bed authority to oversee multiple test beds for urban and complex environments in locations selected on the basis of national and R&D priorities. This joint test bed authority should have authority to undertake the following actions:

- Assess the number of test beds required to meet research, development, and application transitioning needs for the Nation's diverse environments. Implement those test beds consistent with these needs and overall resource constraints.
- Ensure that test bed implementation plans provide for adequate base instrumentation to achieve the intended research, development, and application objectives of the test bed.
- Incorporate user community feedback and advice on user training and technology transition activities at the test beds (supports recommendation 2).
- Coordinate solicitations for competitive proposals to use the test bed infrastructure funded through interagency memoranda of agreement or other mechanisms.
- Provide a point of contact for parties interested in using the test bed for experiments or projects supported by other means.
- Enter into and encourage partnerships with state and local entities, as well as public-private partnerships, for support and utilization of the test beds, in particular for technology transition and user training projects.
- Coordinate the ATD test bed implementation program with other atmospheric modeling test bed efforts.

- Establish and coordinate a program for sharing and archiving long-term measurement data across the ATD test beds, using the data interchange format or guidelines developed for recommendation 3.

Timing considerations for recommendation 4. Implementing and acquiring results from the ATD test beds are evolutionary efforts lasting for a decade and more. Embryonic test beds exist and could be brought up to the level of capability envisioned in this report. Plans for others are developing and must be actively nurtured.

6.4 Develop Standards for Evaluating Modeling System Performance

Accepted standards for evaluating modeling system performance are essential. This need can be met efficiently by the proven processes used by established voluntary standards development organizations such as ASTM International.

Recommendation 5. The OFCM should officially ask an existing standards development organization to establish and maintain a subcommittee to develop guidelines and standards for evaluating ATD modeling system performance. The Federal agencies involved in ATD research, development, or applications are encouraged to support this subcommittee.

Timing considerations for recommendation 5. A working group could be established within an existing consensus standards organization within 6 months. Release of an initial set of performance standards will require 2 to 3 years.

6.5 Improve the Spatial and Temporal Scale Interactions Between Meteorological and ATD Models

As described in section 4.2, there are gaps in model nesting or initialization capability that seriously affect the interactions between models at different spatial and temporal scales. The capability gaps in connecting top-down modeling from NWP-based meteorological models with bottom-up modeling approaches, such as physical modeling, CFD, or LES, are at the very spatial and temporal scales that have major impacts on consequence assessment applications, particularly applications for densely populated environments. One approach is to test and further refine the physical basis for sub-grid-scale parameterization in nested meteorological models. Other approaches to bridging this gap from the microscale or urban scale to mesoscale models should also be investigated.

Another area for improvement is characterization of surface boundary conditions at the three-dimensional spatial scales relevant to ATD modeling requirements in urban environments. Remote sensing from airborne or satellite assets will probably provide the data (see sections 6.6.1 and 6.6.3), but algorithms to test and correct the observation data set will be needed to attain the desired accuracy in model predictions.

Recommendation 6. The R&D communities in meteorological and ATD modeling should work together to conduct the research, development, and testing needed to address difficulties in interfacing models at different scales and to improve the capability of urban scale ATD modeling systems to handle fine-scale surface-atmosphere boundary conditions. Implementation actions include but are not limited to the following.

- Test and refine the physical basis for sub-grid-scale parameterizations. This will be the outcome of the bottom-up approach of using physical models and CFD and LES.
- Explore innovative approaches for bridging the gap from microscale (urban scale) ATD features and events to mesoscale meteorological models.
- Better characterize surface boundary conditions at urban scale, including methods for obtaining, maintaining, and using up-to-date land cover data.
- Address the issues in model initialization, nesting, and data assimilation. This will be the outcome of the top-down approach.

Timing considerations for recommendation 6. No specific timing considerations for this recommendation were identified. However, progress on bridging the gap from microscale ATD features and events to mesoscale meteorological model results used as initialization and boundary data in ATD modeling is essential to reducing the uncertainties in ATD predictions.

6.6 Improve Measurement Technology

6.6.1 Coordinated Measurements Technology Development Program

Measurements provide the ground truth for models and theory, as well as the data for model initialization and bounding. For progress in theory and modeling and for understanding the uncertainty in model variables, measurements of concentrations and atmospheric variables must be made at or below the scales of interest. Test beds will not realize their full potential with point sensors alone. Capabilities to remotely sense meteorological fields of wind, turbulence, and moisture fluxes rapidly and volumetrically should be actively pursued and quickly incorporated into test beds for evaluation and utilization. Technology to rapidly sense induced tracers in situ and remotely is essential for test beds and for special experiments. Some sensing systems must be mobile, rather than fixed at one location. In emergency response applications, airborne or ground-transportable systems are highly desirable for plume tracking throughout the depth of the boundary layer and not just at ground level.

Avenues already in place for instrumentation R&D can be leveraged for ATD instrumentation development. Many Federal agencies have small business innovative research (SBIR) and/or small business technology transfer (STTR) programs. These could be used as vehicles for a multiagency approach to enlisting the resources of the private sector and the university research community in innovative instrumentation technology R&D. The “bench scientists” in the Federal laboratories have creative ideas

and capabilities to develop new instrumentation providing these measurement capabilities.

Recommendation 7. A coordinated Federal ATD R&D program should develop or improve evolutionary and revolutionary atmospheric sensors supporting ATD R&D and then transition the technology into tools for ATD model researchers, developers, and users. This coordinated program for measurement technology should tap the expertise from across the public (including Federal laboratories), private, and academic sectors. Implementation actions required for this recommendation include but are not limited to the following.

- Identify potential tracer materials and determine the most useful combinations of tracer material and detection techniques to improve ATD models and quantify uncertainty.
- Develop and test new atmospheric measurement technology, including those using remote-sensing techniques for volumetric measurements.
- Coordinate measurement technology development with modeling R&D (see Recommendations 1 and 6) to address major model–data interface issues, including but not limited to sensor fusion, data assimilation, and evaluation criteria.

Timing considerations for recommendation 7. Timing and priorities among the suggested implementation actions should reflect dependency relationships with other ATD R&D activities. For example, a reliable and cost-effective means for collecting large amounts of tracer data is essential for characterizing and quantifying the uncertainty in ATD predictions. Therefore, an early start, with high priority, should be given to selecting potential tracer materials. This selection should be completed within 2 years because it will dictate the direction of development for point and volumetric techniques for tracer measurement. Engineering development to lower cost and enhance mobility of sensor networks relative to existing systems could, if initiated soon, be completed within 5 years. Development and test of new, innovative systems for meteorological measurements will be an ongoing process, continuing over a decade and more.

6.6.2 Instrument Siting and Networking

Guidelines for siting sensors for meteorological variables or processes have generally been developed for open environments. In the complexities of urban, coastal, or terrain environments, these guidelines can rarely be met. The existing criteria are suitable for their intended purpose of observations to support regional weather forecasting. However, in urban environments, there are multiple purposes that meteorological sensor systems can serve. The CFD modeling community may want time-sequenced data near buildings, as well as away from buildings, to discern circulation patterns. To ensure that consistent and reliable measurements are made at ATD test beds, performance guidelines need to be established for siting instrumentation in complex environments that take these multiple purposes into account. Given the rapid advance in instrumentation technologies and the variability from site to site in terrain and local meteorological characteristics (e.g., diurnal

wind patterns, air-land-water circulation and heat transfer patterns), traditional, deterministic design requirements for instrument siting are unlikely to work well for the intended purposes. Functional guidelines, in terms of desired performance from an instrumented site, are more appropriate.

Recommendation 8. The OFCM should establish a working group, representing the Federal agencies involved in ATD research, development, or applications, to establish performance guidelines for ATD and meteorological instrumentation systems in complex environments. Implementation actions for this recommendation include but are not limited to developing and testing procedures for designing local observation networks and siting instrumentation in diverse, complex environments.

Timing considerations for recommendation 8. A working group can be established through the OFCM in 3 months. Release of draft instrumentation performance guidelines will require about a year after that. Test of the guidelines will follow as required.

6.7 Design and Conduct Special Studies and Experiments

Many of the classic field transport and diffusion experiments upon which our modeling parameters are based date back to the 1950s to 1970s. Since then, significant advances have occurred in measurement technology, computational capabilities, and modeling algorithms. Among these advances are major reductions in the averaging times for meteorological or tracer sampling. Turbulence and its spatial variability are better characterized and captured in model representations. The importance of boundary-layer scaling has been demonstrated.

Special field studies, replicating several of the classical studies, should be conducted with modern measurement technology. Such studies will improve the data foundation for model parameterization, assess the improvements in understanding gained from advances in science, and demonstrate the merits of new measurement technologies. Another reason for special studies is to provide an adjunct to the fixed test beds, allowing other environmental settings to be studied and to extend model testing and verification and validation (V&V) to these settings. A key ingredient for such studies is the ability to measure tracer concentrations remotely in four dimensions at high space-time resolution and meaningful concentrations.

Like the design of the ATD test beds, design of special studies and experiments conducted at non-test bed sites should be informed by the results of the data capture and reanalysis efforts recommended in section 6.2 (see recommendation 4). These special studies will also prove more fruitful after some of the measurement technology improvements recommended in section 6.5 are available for use in them. Given these prerequisites and the high priority of proceeding with test bed implementation, special studies and experiments are intermediate-term to longer-term needs (3 to 7 years).

Recommendation 9. The Federal agencies involved in ATD research, development, or applications should establish a working group to design and oversee the conduct of a series of classical experiments. The design and selection of these experiments should

reflect the information gained by capturing existing data (recommendation 3) and complement the infrastructure of ATD modeling system test beds (recommendation 4). Among experiments that the working group should consider are the following:

- Characterize fundamental uncertainty (due to atmospheric turbulence) through highly instrumented testing under simplified conditions (a “Daughter of Prairie Grass” study but incorporating new technology).
- A regional-scale study (covering about 5000 km²) of the diurnal evolution of tracer transport and diffusion in the ABL in terrain-forced flows should be achieved within a decade. Such a study should use newly developed tracer technology to enable surface and airborne multidimensional remote sensing of concentration, even between urban structures. Surface and airborne networked Doppler lidar systems with overlapping coverage could be used to measure winds, turbulence, and stratified aerosol layers. The study should include low-altitude temperature and turbulence measurements for turbulence fluxes and a network of other measurement systems designed and deployed for the study location.

Timing considerations for recommendation 9. At least 3 years will be needed before new experiments can be defined and designed, depending on progress in reanalyzing old data sets (recommendation 3) and improving measurement technologies (recommendations 7 and 8).

